



北京大学
PEKING UNIVERSITY

“晨光杯青年优秀论文”终评答辩

Belle实验上粲重子 E_c 绝对分支比的首次测量



Phys. Rev. Lett. 122, 082001 (2019)

Phys. Rev. D 100, 031101(R) (2019)

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2021年08月16日

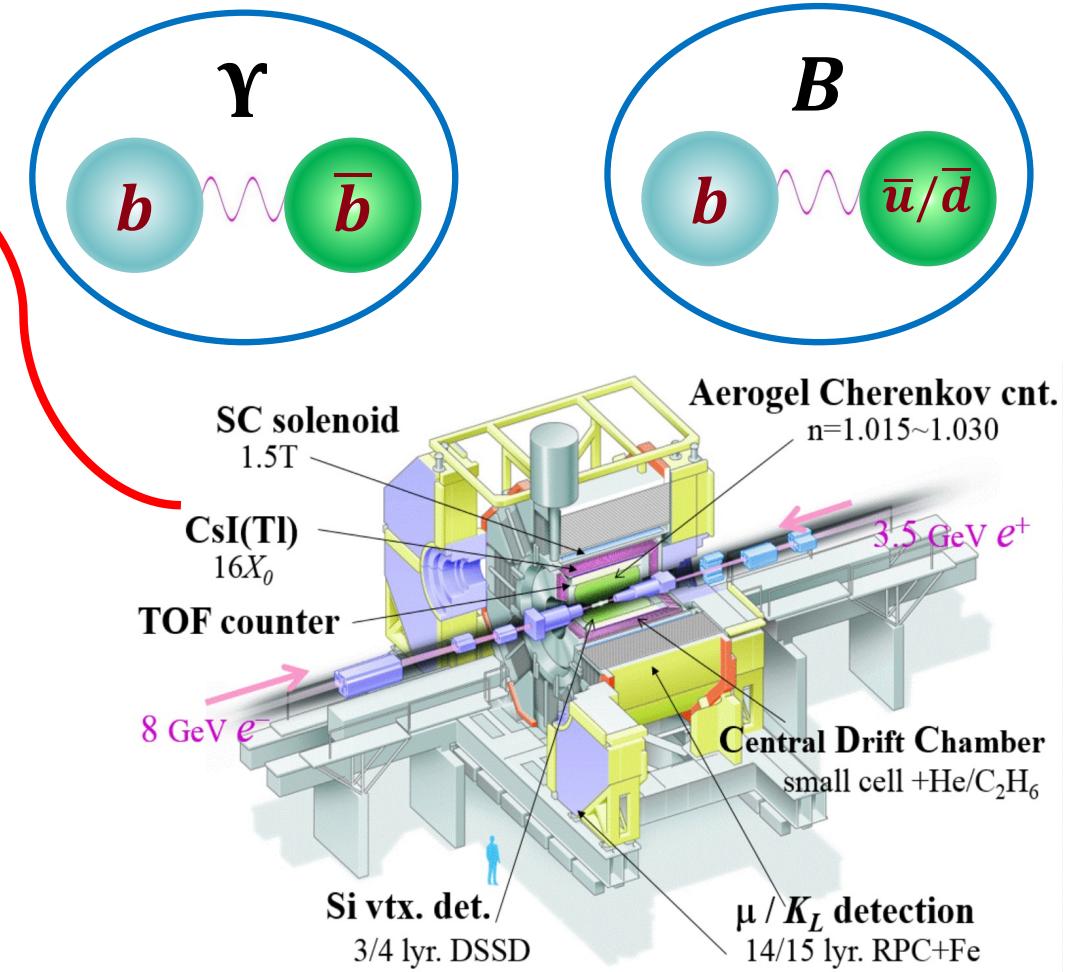
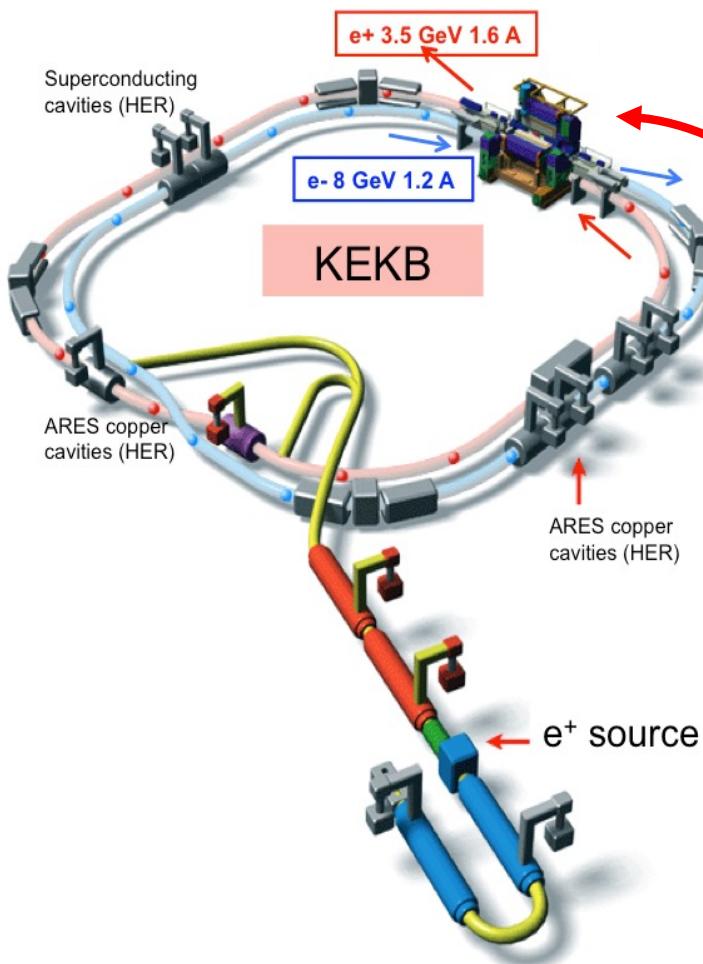
提纲

- Belle实验简介
- 研究背景介绍
- 实验方法和结果
- 总结与展望

Belle实验简介



Belle 探测器: 4π 通用谱仪, 共采集 980 fb^{-1} 是数据。
其中包含 772×10^6 个 $e^+e^- \rightarrow \gamma(4S) \rightarrow B\bar{B}$



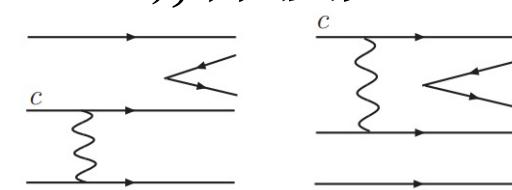
研究背景介绍

- 描述强相互作用：量子色动力学(QCD)

- 高能区：微扰展开
 - 低能区：唯象模型→误差大，需要试验输入参数
 - 粱夸克质量位于微扰和非微扰的过渡能区

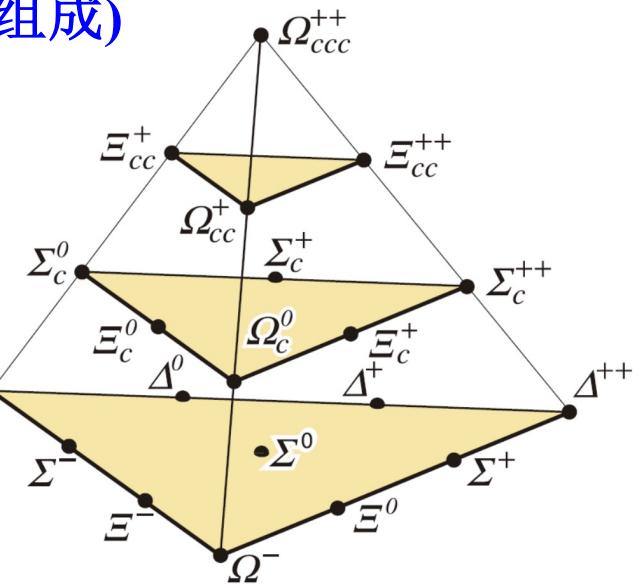
- 粱重子：含有一个c夸克的重子(由三个夸克组成)

- 对比与粱介子(两个夸克组成),有较大不可因子化的W交换过程贡献。



- 末态超子宇称破缺→可研究宇称破坏

- 检验重味夸克对称性和轻夸克手征对称性理想场所



研究背景介绍

对撞后强子化:

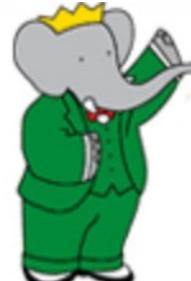
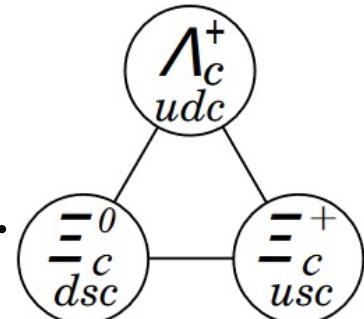
$$e^+ e^- \rightarrow \Lambda_c^+ D^{(*)-} \bar{p} \pi^+$$

$$e^+ e^- \rightarrow \Lambda_c^+ \bar{\Lambda}_c^-$$

产率低/本底高

对于 $SU(3)$ 反三重态，只有 Λ_c^+ 的绝对衰变
分支比被 Belle [PRL 113, 042002]

和 BESIII [PRL 116, 052001] 实验测量。



重味强子的衰变:

$$B^- \rightarrow \bar{\Lambda}_c^- \Xi_c^0$$

$$\Xi_{cc}^{++} \rightarrow \Xi_c^+ \pi^+$$

难以标记

但是发现 Ξ_c^0 [PRL 62, 863(1989)] 和 Ξ_c^+ [PLB 122, 455(1983)]

30年后，它们的绝对衰变分支比依旧没有被测量。

➤ $\Xi_c^0 \rightarrow \Xi^- \pi^+$ 和 $\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+$ 作为参考道，其他 Ξ_c^0 和 Ξ_c^+ 的衰变分支比都给出其相对它们的比值。

研究背景介绍

- 理论更为需要的输入参数：绝对衰变分支比
- $\Xi_c^0 \rightarrow pK^-K^-\pi^+$ 和 $\Xi_c^+ \rightarrow pK^-\pi^+$ 是 LHCb 重建 Ξ_c 的基本衰变道。
其衰变分支比是研究重味重子及其激发态和双粲重子性质的重要输入参数
 - $\Xi_{cc}^{++} \rightarrow \Xi_c^+ \pi^+$ [PRL 121, 162002 (2018)]
 - $\Xi_b^- \rightarrow \Xi_c^0 \pi^-$ [PRL 113, 242002 (2014)]
 - $\Omega_c(3000, 3050, 3066, 3090, 3119)^0 \rightarrow \Xi_c^+ K^-$ [PRL 113, 242002 (2014)]
- 部分理论计算：
 - $\mathcal{B}(\Xi_c^0 \rightarrow \Xi^-\pi^+) \approx 1.12\% \text{ 或 } 0.74\%$ [PRD48,4188]
 - $\mathcal{B}(\Xi_c^+ \rightarrow \Xi^-\pi^+\pi^+) = (1.47 \pm 0.84)\%$ [PRD97,073006]
 - $\mathcal{B}(\Xi_c^+ \rightarrow pK^-\pi^+) = (2.2 \pm 0.8)\%$ [EPJC78,224; CPC42, 051001]
- 理论计算 $B \rightarrow \Lambda_c^-\Xi_c$ 衰变分支比在 10^{-3} 量级 [PRD 73, 074015 (2006)]

在 belle 实验上分析 $B \rightarrow \Lambda_c^-\Xi_c$
成为测量 Ξ_c 绝对衰变分支比的突破口

实验方法

◆ 分支比测量方法

Ξ_c 遍举衰变

$$\mathcal{B}(\Xi_c \rightarrow xxx) = \frac{\mathcal{B}(B \rightarrow \Lambda_c^- \Xi_c) \mathcal{B}(\Xi_c \rightarrow xxx)}{\mathcal{B}(B \rightarrow \Lambda_c^- \Xi_c)} \longrightarrow \Xi_c \text{ 单举衰变}$$

◆ 重建末态

可以消耗以下系统误差:

径迹重建, 粒子鉴别, Λ_c 重建和 B 介子总数

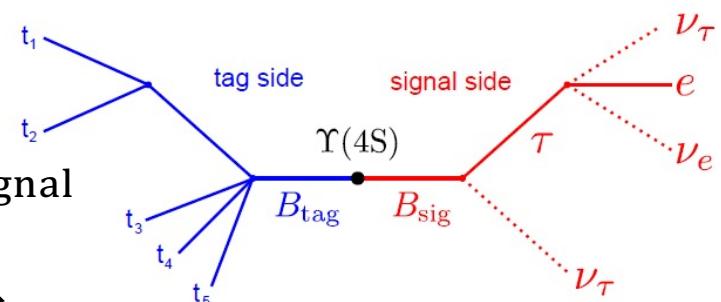
Ξ_c^+	$\bar{B}^0 \rightarrow \bar{\Lambda}_c^- \Xi_c^+$,	$\Xi_c^+ \rightarrow \text{anthing}$
		$\Xi_c^+ \rightarrow \Xi^-(\Lambda\pi^-)\pi^+\pi^+$
		$\Xi_c^+ \rightarrow pK^-\pi^+$
Ξ_c^0	$B^- \rightarrow \bar{\Lambda}_c^- \Xi_c^0$,	$\Xi_c^0 \rightarrow \text{anthing}$
		$\Xi_c^0 \rightarrow \Xi^-(\Lambda\pi^-)\pi^+$
		$\Xi_c^0 \rightarrow \Lambda(p\pi)K^-\pi^+$
		$\Xi_c^0 \rightarrow pK^-K^-\pi^+$

$$\left. \begin{array}{l} \Lambda_c \rightarrow pK\pi \\ \text{Phys. Rev. D 100, 031101(R) (2019)} \end{array} \right\} \quad \Lambda_c \rightarrow pK\pi, pK_s^0(\pi\pi) \\ \text{Phys. Rev. Lett. 122, 082001 (2019)}$$

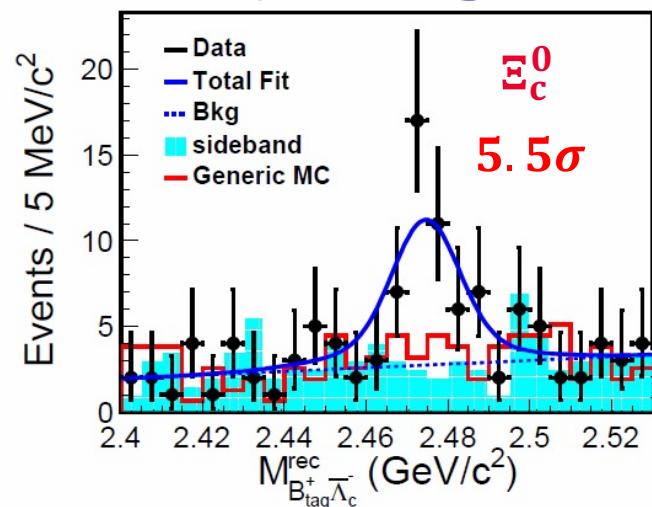
实验方法和结果

◆ B 介子标记算法

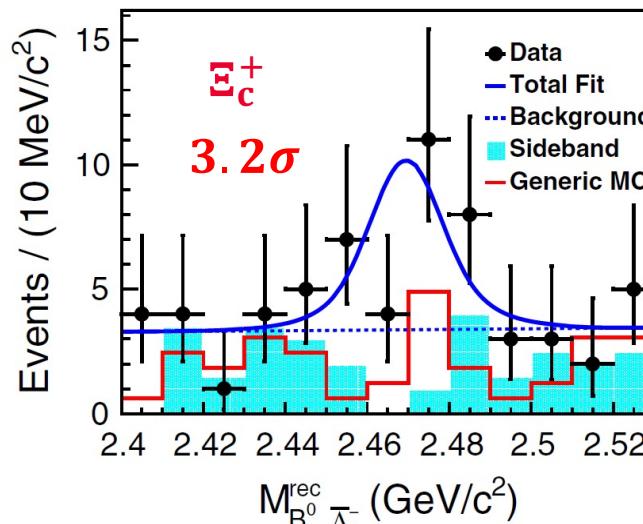
- B 介子来源: $e^+e^- \rightarrow \gamma(4S) \rightarrow B\bar{B}$
- 若重建一个 B_{tag} , 那么未重建的部分来自 B_{signal}
- B 介子没有分支比较大的遍举衰变道
- 使用1042种 B 介子衰变道, 构建71个神经网络
- 最终 B_{tag} 的重建效率是: B^- : 0.36%, B^0 : 0.24%



◆ $\Xi_c \rightarrow \text{anythings}$ 单举信号



$$N_{\Xi_c^0} = 40.9 \pm 9.0$$



$$N_{\Xi_c^+} = 18.8 \pm 6.8$$

在 $B_{tag}\bar{\Lambda}_c^-$ 的反冲质量谱上，观测到了 Ξ_c^+ 的信号

$$\mathcal{B}(B \rightarrow \Lambda_c^- \Xi_c)$$

实验结果

Ξ_c^+ 遍举衰变信号提取

$$\mathcal{B}(B \rightarrow \Lambda_c^- \Xi_c) \mathcal{B}(\Xi_c \rightarrow xxx)$$

信号产率通过对 M_{bc} 和 ΔE 进行二维拟合得到

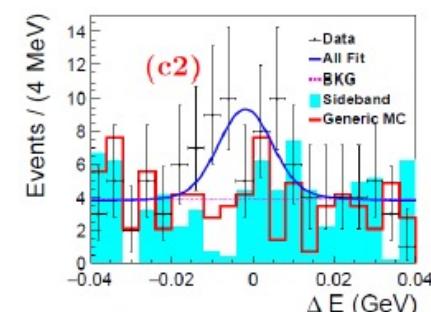
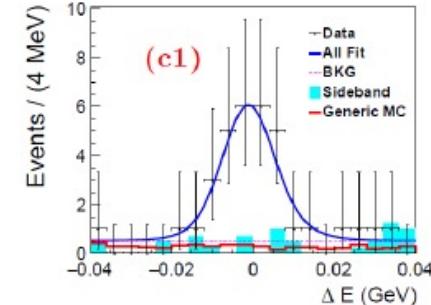
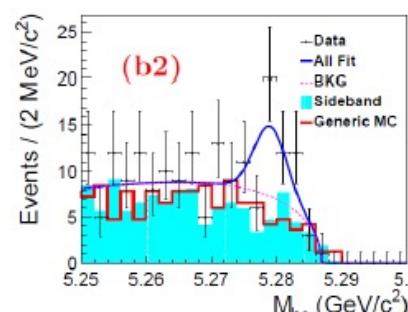
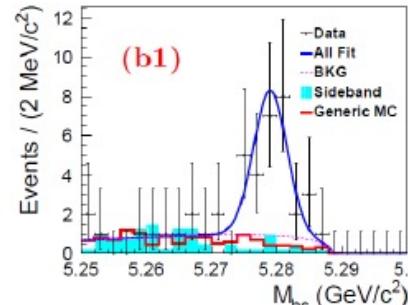
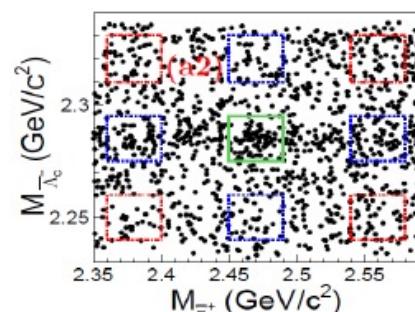
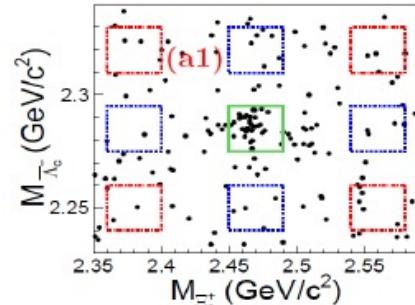
$$M_{bc} = \sqrt{E_{\text{beam}}^2 - \vec{p}_{\text{signal } B}^2} \quad \Delta E = E_{\text{signal } B} - E_{\text{Beam}}$$

$$\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+ \\ N = 24.2 \pm 5.4$$

6.9σ

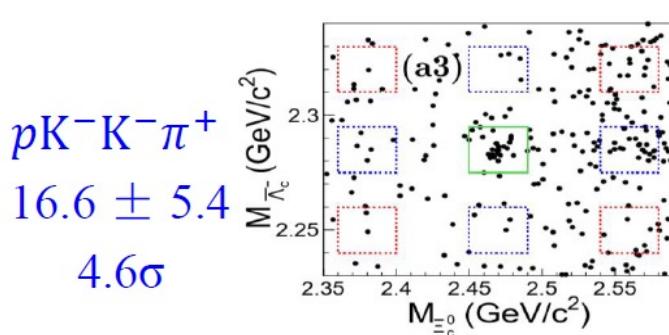
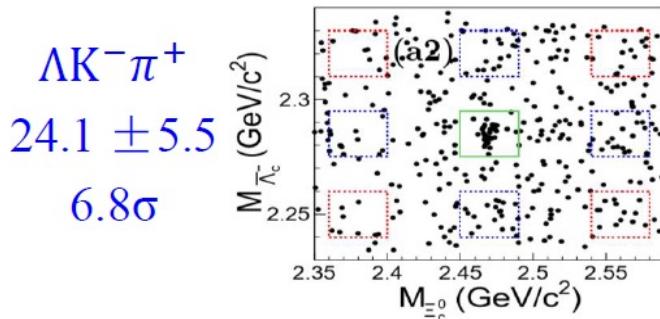
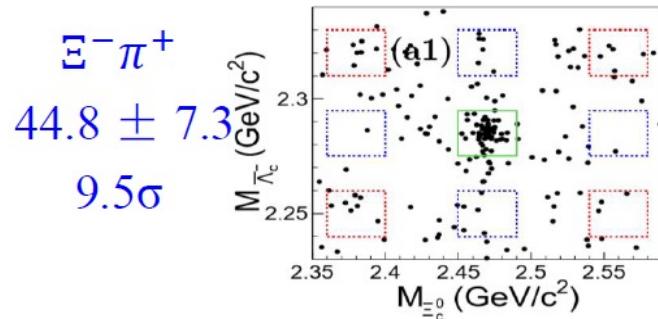
$$\Xi_c^+ \rightarrow p K^- \pi^+ \\ N = 24.0 \pm 6.9$$

4.5σ

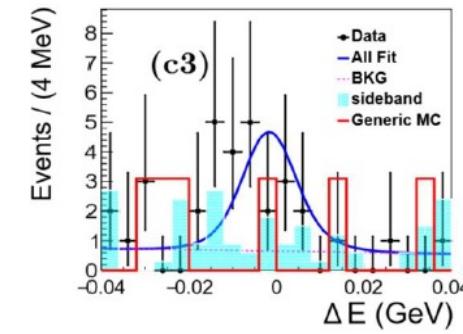
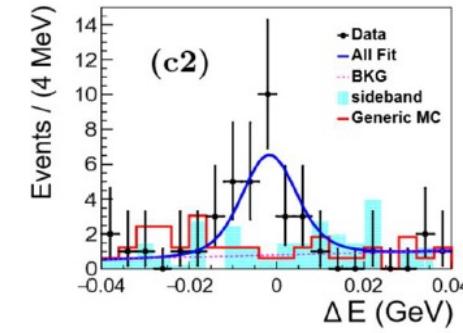
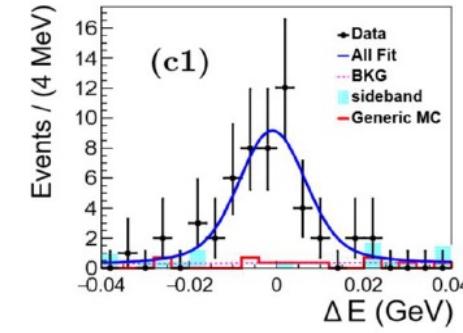
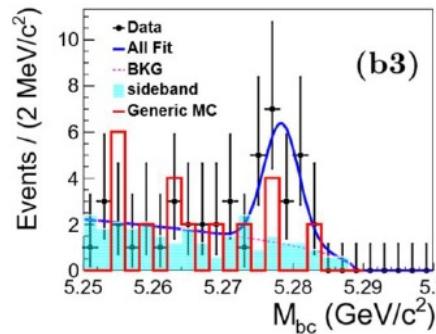
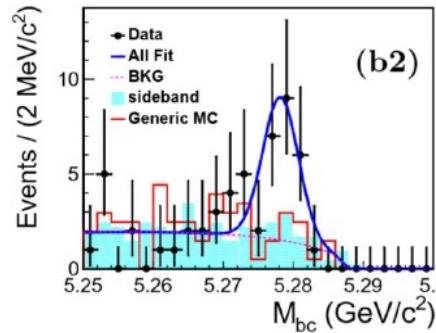
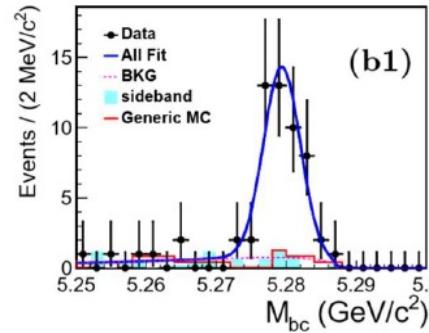


实验结果

Ξ_c^0 遍举衰变信号提取



Ξ_c^0 遍举衰变信号提取



总结与展望

- ◆首次利用 B 介子标记技术，通过反冲研究粲重子
- ◆在 $\Xi_c^{0,+}$ 被发现30年后，首次测量了其绝对衰变分支比
- ◆截至目前，两篇文章分别被引用34和23次。

Ξ_c^0	
$\mathcal{B}(\Xi_c^0 \rightarrow \Xi^- \pi^+)$	$(1.80 \pm 0.50 \pm 0.14)\%$
$\mathcal{B}(\Xi_c^0 \rightarrow \Lambda K^- \pi^+)$	$(1.17 \pm 0.37 \pm 0.09)\%$
$\mathcal{B}(\Xi_c^0 \rightarrow p K^- K^- \pi^+)$	$(0.58 \pm 0.23 \pm 0.05)\%$

First Measurements of Absolute Branching Fractions of the Ξ_c^0 Baryon at Belle
Belle Collaboration • [Y.B. Li \(Peking U.\) et al.](#) (Nov 23, 2018)

Published in: *Phys.Rev.Lett.* 122 (2019) 8, 082001 • e-Print: [1811.09738](#) [hep-ex]

pdf DOI cite

34 citations

Ξ_c^+	
$\mathcal{B}(\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+)$	$(2.86 \pm 1.21 \pm 0.38)\%$
$\mathcal{B}(\Xi_c^+ \rightarrow p K^- \pi^+)$	$(0.45 \pm 0.21 \pm 0.07)\%$

First measurements of absolute branching fractions of the Ξ_c^+ baryon at Belle
Belle Collaboration • [Y.B. Li \(Peking U.\) et al.](#) (Apr 26, 2019)

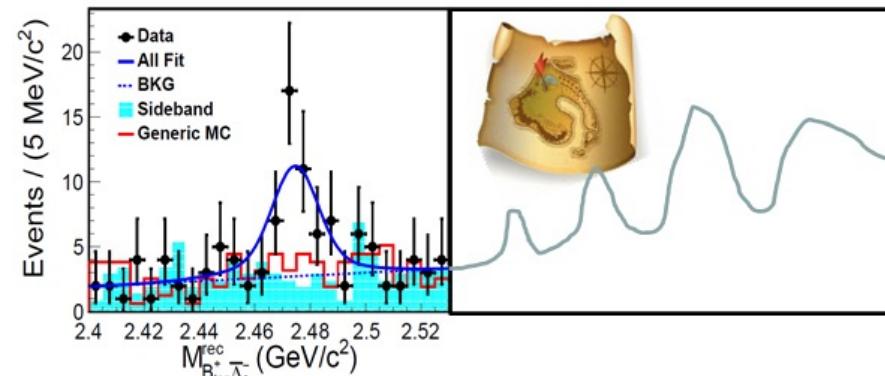
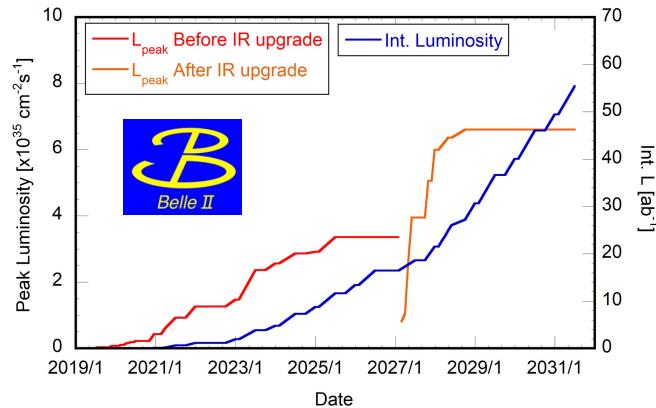
Published in: *Phys.Rev.D* 100 (2019) 3, 031101 • e-Print: [1904.12093](#) [hep-ex]

pdf DOI cite

23 citations

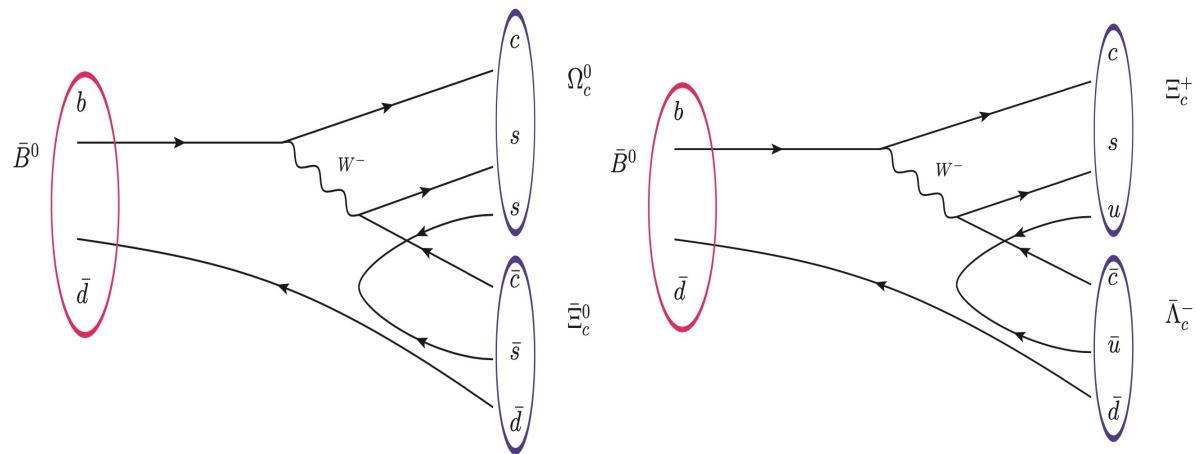
总结与展望

- ◆ 开启了利用 B 介子反冲技术研究粲重子的新思路
- ◆ Belle II 已经正式开始运行：高精度，高亮度



- ◆ Ξ_c 激发态的性质测量，甚至发现新的激发态？半轻衰变形状因子！
- ◆ 其他粒子性质测量？
共同为理解强相互作用
提供实验输入参数。

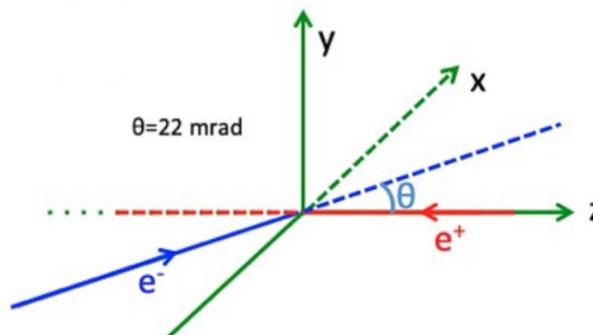
谢谢！



Backup : Belle实验简介



- Hosted by High Energy Accelerator Research Organization in Tsukuba, Japan
- Once World highest luminosity $e^+ e^-$ collider:
Peak Luminosity: $2.11 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
- Data taking: 1999 – 2010

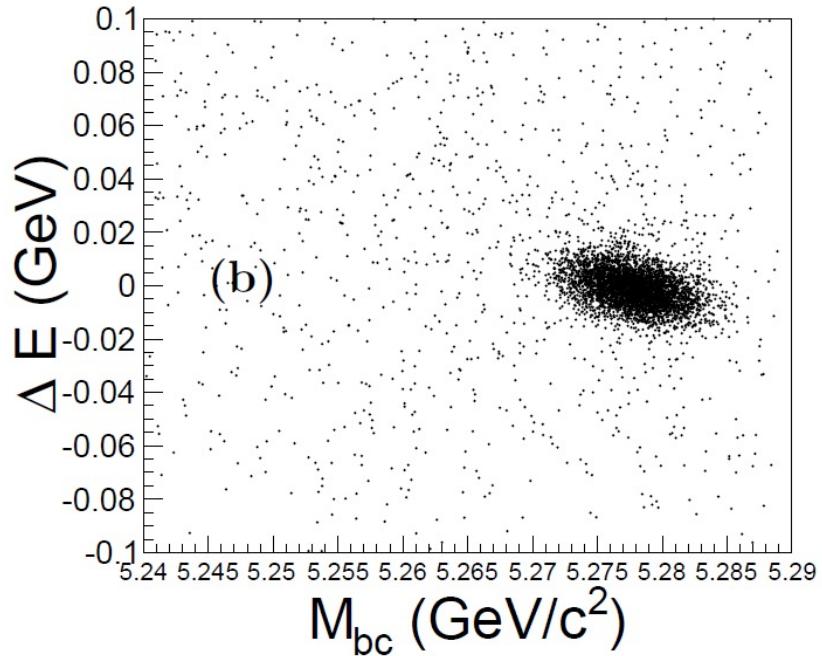
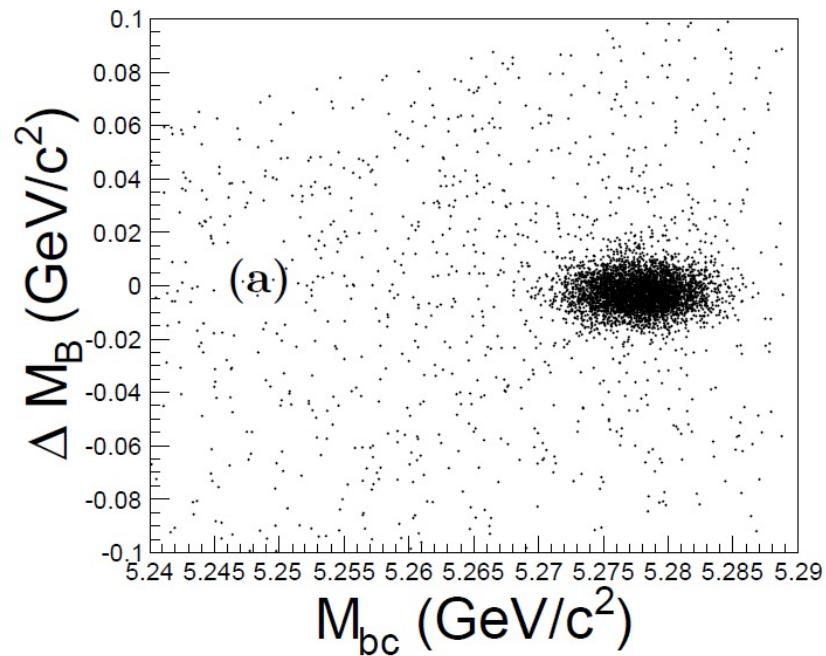


LER: 3.5 GeV

HER: 8.0 GeV

$\theta = 22 \text{ mrad}$

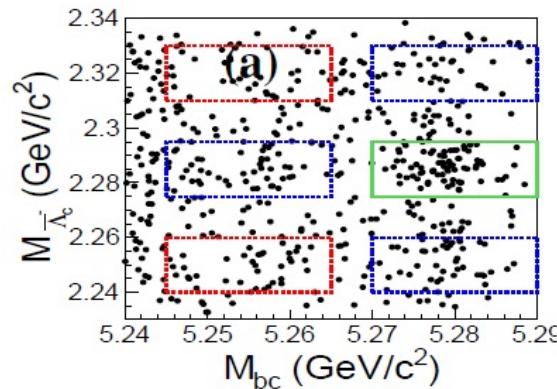
When drawing 2D fitting plot of M_{bc} and ΔM_B ,
the $M_{bc} > 5.27 \text{ GeV}/c^2$ or $|\Delta M_B| < 0.018 \text{ GeV}/c^2$ (3σ) is applied



We didn't use ΔE because it shows clear correlation with M_{bc} but ΔM_B doesn't.

E_c⁰ inclusive decay

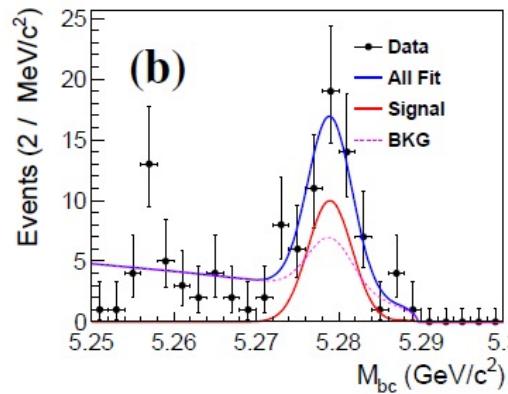
Perform 2D fit on M_{bc} v.s. $M_{\bar{\Lambda}_c^-}$



double-Gaussian functions
for M_{bc} signal

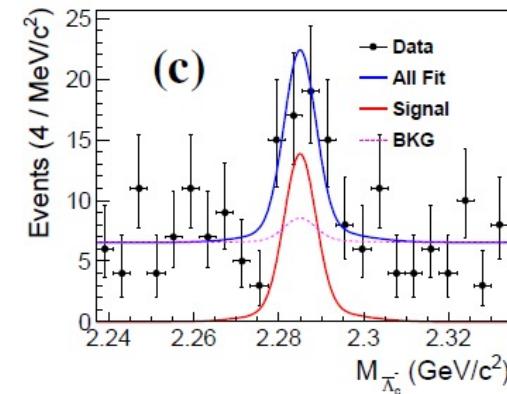
$$f(M_1, M_2) = N^{sig} s_1(M_1) s_2(M_2) + N_{sb}^{bg} s_1(M_1) b_2(M_2) + N_{bs}^{bg} b_1(M_1) s_2(M_2) + N_{bb}^{bg} b_1(M_1) b_2(M_2).$$

ARGUS function for M_{bc} BKG



double-Gaussian functions
for M_{Λ_c} signal

1st-order Chebyshev polynomial function
for $M_{\bar{\Lambda}_c^-}$ BKG



Fit results:

$$N_{sig} = 36.2 \pm 8.9$$

5.4σ

Signal region:

$$M_{bc} > 5.27 \text{ GeV}/c^2$$

$$|M_{\bar{\Lambda}_c^-} - m_{\bar{\Lambda}_c^-}| < 10 \text{ MeV}/c^2$$

- Sideband:

$\frac{1}{2}$ red boxes - $\frac{1}{4}$ blue boxes

实验结果

衰变道	分支比	理论预言值	PDG
$\mathcal{B}(B^- \rightarrow \bar{\Lambda}_c^- \Xi_c^0)$	$(9.51 \pm 2.10 \pm 0.88) \times 10^{-4}$	$\sim 10^{-3}$	
$\mathcal{B}(B^- \rightarrow \bar{\Lambda}_c^- \Xi_c^0) \mathcal{B}(\Xi_c^0 \rightarrow \Xi^- \pi^+)$	$(1.71 \pm 0.28 \pm 0.15) \times 10^{-5}$		$(2.4 \pm 0.9) \times 10^{-5}$
$\mathcal{B}(B^- \rightarrow \bar{\Lambda}_c^- \Xi_c^0) \mathcal{B}(\Xi_c^0 \rightarrow \Lambda K^- \pi^+)$	$(1.11 \pm 0.26 \pm 0.10) \times 10^{-5}$		$(2.1 \pm 0.9) \times 10^{-5}$
$\mathcal{B}(B^- \rightarrow \bar{\Lambda}_c^- \Xi_c^0) \mathcal{B}(\Xi_c^0 \rightarrow p K^- K^- \pi^+)$	$(5.47 \pm 1.78 \pm 0.57) \times 10^{-6}$		
$\mathcal{B}(\Xi_c^0 \rightarrow \Xi^- \pi^+)$	$(1.80 \pm 0.50 \pm 0.14)\%$	$0.74 \sim 1.12\%$	
$\mathcal{B}(\Xi_c^0 \rightarrow \Lambda K^- \pi^+)$	$(1.17 \pm 0.37 \pm 0.09)\%$		
$\mathcal{B}(\Xi_c^0 \rightarrow p K^- K^- \pi^+)$	$(0.58 \pm 0.23 \pm 0.05)\%$		
$\mathcal{B}(\Xi_c^0 \rightarrow \Lambda K^- \pi^+) / \mathcal{B}(\Xi_c^0 \rightarrow \Xi^- \pi^+)$	$0.65 \pm 0.18 \pm 0.04$		1.07 ± 0.14
$\mathcal{B}(\Xi_c^0 \rightarrow p K^- K^- \pi^+) / \mathcal{B}(\Xi_c^0 \rightarrow \Xi^- \pi^+)$	$0.32 \pm 0.12 \pm 0.07$		0.34 ± 0.04
$\mathcal{B}(\bar{B}^0 \rightarrow \bar{\Lambda}_c^- \Xi_c^+)$	$(1.16 \pm 0.42 \pm 0.15) \times 10^{-3}$	$\sim 10^{-3}$	
$\mathcal{B}(\bar{B}^0 \rightarrow \bar{\Lambda}_c^- \Xi_c^+) \mathcal{B}(\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+)$	$(3.32 \pm 0.74 \pm 0.33) \times 10^{-5}$		$(1.8 \pm 1.8) \times 10^{-5}$
$\mathcal{B}(\bar{B}^0 \rightarrow \bar{\Lambda}_c^- \Xi_c^+) \mathcal{B}(\Xi_c^+ \rightarrow p K^- \pi^+)$	$(5.27 \pm 1.51 \pm 0.69) \times 10^{-5}$		
$\mathcal{B}(\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+)$	$(2.86 \pm 1.21 \pm 0.38)\%$	$(1.47 \pm 0.84)\%$	
$\mathcal{B}(\Xi_c^+ \rightarrow p K^- \pi^+)$	$(0.45 \pm 0.21 \pm 0.07)\%$	$(2.2 \pm 0.8)\%$	
$\mathcal{B}(\Xi_c^+ \rightarrow p K^- \pi^+) / \mathcal{B}(\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+)$	$0.16 \pm 0.06 \pm 0.02$		0.21 ± 0.04

referee评价

This paper presents the first absolute branching fractions (BF) of $X\bar{s}i^0_c$ baryons into 3 decay modes. It uses **novel methods** developed by the Belle II collaboration to reconstruct fully the kinematic of a B-meson on one side, based on a powerful artificial Neural Network method Nucl. Instrum. Meth. A 654 432-440,2011, that improves dramatically the efficiency of the recoil-B determination and **exploit much better** the recorded data by Belle about a decade ago.

This measurement is **certainly useful for the LHCb** experiment at CERN that can study baryon-b decays that may involve $X\bar{s}i^0_c$ baryon, and this measurement is also **of interest for validation of QCD model that compute the above decays**.

The paper reports the first measurement of the absolute branching fraction of the $Xic0$ baryon which will **have a large impact on testing the models predicting the properties of the charmed baryons**. The paper is clear and well written in every sections. Therefore I recommend its publication after addressing the few comments and questions below.